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A Study of H II Regions in Spiral Galaxies Using Multiobject Spectroscopy

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ABSTRACT

We present results from multiobject spectroscopy of H II regions in nearby late-type spiral galaxies. Our results include excitation measurements, log ([O III]/Hβ), for 81 regions in M 101, 30 regions in NGC 2403, and 13 regions in M 51. We conclude that late-type spirals can be classified into two distinct populations, examine possible causes of this division, and derive metallicity gradients for these galaxies. M 51 appears to have an anomalously shallow abundance gradient.

Before the advent of multiobject spectroscopy only one galaxy, M 33, had excitations, log([O III]/Hβ), measured for more than 30 of its H II regions. In fact, excitation and metallicity gradients for most galaxies are derived from measurements of roughly 10 regions. Since the development of multiobject spectroscopy, we have presented excitation measurements for 45 regions in M 33 (Zaritsky, Elston, and Hill 1989a; Paper I) and Walsh and Roy (1989) have presented measurements for 49 regions in NGC 2997. In this paper, we present results from observations of 81 regions in M 101, 30 regions in NGC 2403, and 13 regions in M 51. Multiobject spectroscopy provides the opportunity to observe a large number of regions in a fraction of the observing time previously required.

The observations were made using the MX Spectrometer on the Steward Observatory 90 in.(2.3 m) telescope on Kitt Peak. MX is a multiaperture spectrometer equipped with optical fibers that are attached to microprocessor controlled mobile probes. There are 32, 4 arcsec aperture object-designated fibers. An 832 gpm grating in second order centered at $\approx$ 4800 Å provided a spectral scale of 0.7Å per pixel. Typical exposure times were about 1 hour. For more details of the observing procedure, data reduction, and error estimation see Paper I and Zaritsky, Elston, and Hill (1989b).

In Figure 1a we present the data for M 33 (from Paper I), M 51 (data from this study and from Searle (1971) and Smith (1975)), M 101, NGC 2403, and NGC 2997 (from Walsh and Roy 1989). It is apparent that these five galaxies can be sorted into two distinct groups with very little overlap. The demarcation between the two groups becomes more striking when one considers that the scatter in excitation measurements for a single galaxy at a given radius can be as large as 1 dex. We have used these data as the training sample with which to construct a classification scheme. The classification scheme was then applied to data from the literature for Sbc to Scd type galaxies for which at least five H II regions have been observed (from Searle 1971, Smith 1975, Pagel *et al.* 1979, Dufour *et al.* 1980, Edmunds and Pagel 1984, and McCall *et al.* 1985). The results are presented in Figure 1b. The misclassification percentage (a regions is termed misclassified if its classification is different than that of the majority of the regions in its parent galaxy) is less than 9%, with many of the misclassified regions being less than 1σ away from the dividing line. Even if with additional data the division between the groups disappears, it is clear that there are significant global differences in excitation among late-type galaxies.

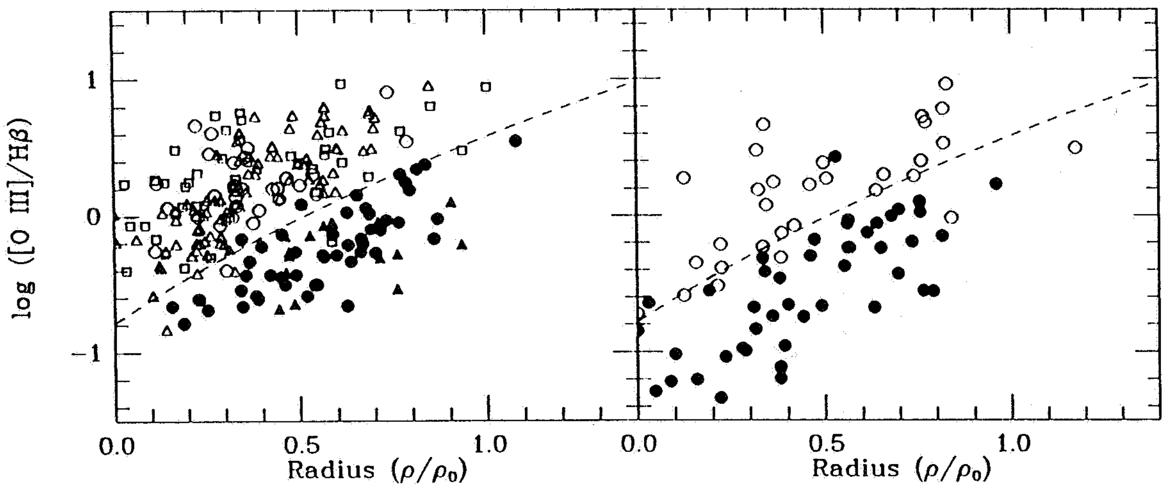

Figure 1a (left) - M 101 (open triangles), M33 (open squares), NGC 2403 (open circles), NGC 2997 (solid circles), and M 51 (solid triangles). Dashed line indicates division between proposed populations. Figure 1b (right) - Data from literature for NGC 300, NGC 628, NGC 2403, NGC 3344, NGC 4736, NGC 5068, NGC 7793, M 33, and M 101 (open circles). Data from literature for NGC 1635, NGC 2903, NGC 2997, NGC 3184, NGC 3351, NGC 4254, NGC 4321, NGC 5055, NGC 6946, IC 342, M 51, and M 83 (solid circles).

Excitation is a function of the dust content, the ionizing radiation field, and the abundance of the H II region. Searle (1971) argued against the first two parameters when discussing the cause of the excitation gradients in galaxies by citing the lack of radial variations in either $H\alpha/H\beta$ (sensitive to dust), or in I(He I λ5876)/I($H\beta$) (sensitive to high energy photons). We examined whether variations in dust content or ionizing field could produce the global excitation differences between galaxies. There is no clear division between the distributions of either $H\alpha/H\beta$ or I(He I λ5876)/I($H\beta$) for the two groups; therefore, we conclude that neither dust content nor ionizing field is the primary cause of the grouping in Figure 1.

It has been suggested (McCall 1982) that metal abundance be plotted as a function of fractional effective radius or surface mass density instead of fractional isophotal radius. The reasoning is that both of these quantities provide better physical descriptions. In support of this, we find that when excitation is plotted against either of these quantities, the data fall more nearly on a single curve. However, there is still strong segregation between the groups and in the case of the relationship between excitation and fractional effective radius, more scatter than when excitation is plotted against fractional isophotal radius.

We have applied the empirical calibration of log([O III]/$H\beta$) (Edmunds and Pagel 1984) to estimate the oxygen abundance of the observed H II regions. Empirical calibrations rely on a statistical relationship between the observed line ratios and abundance. Multiobject spectroscopy compliments this technique by providing a large number of measurements at a given radius, thereby allowing for an accurate statistical measurement of the metal abundance at that radius, provided the empirical calibration is correct. The abundance gradients we measure for M 33, M 51, M 101, NGC 2403, and NGC 2997 using this empirical calibration are -0.098 ± 0.027, -0.042 ± 0.010, -0.072 ± 0.006, -0.089 ± 0.033, -0.093 ± 0.010 dex kpc^{-1}, respectively. Previous measurements are -0.01 ± 0.03 (using

data from Kwitter and Aller 1981), -0.081 ± 0.027 (Tosi and Diaz 1985), -0.074 ± 0.006 (Evans 1986), -0.083 ± 0.032 (Tosi and Diaz 1985), and 0.084 (Walsh and Roy 1989), for M 33, M 51, M101, NGC 2403, and NGC 2997 respectively. The excellent agreement ($< 1\sigma$) between the gradients derived for M 33, M101, NGC 2403 and NGC 2997 imply that the empirical calibration for excitation when used in conjunction with measurements of over 30 H II regions produces results at least as accurate and precise as those obtained from a combination of the favored empirical calibration, that of ([O II] + [O III])/Hβ, and detailed modelling. The derived gradient for M 51 is in marginal agreement ($< 2\sigma$) with the previous determination, but the difference is due entirely to the additional regions, not to the abundance calculations.

In conclusion, we have discussed briefly some of the preliminary results from multi-aperture spectroscopy of H II regions in some nearby late-type spiral galaxies, M 33, M 51, M 101, NGC 2403, NGC 2997. We conclude that late-type spirals can be classified into two distinct groups based on the excitation of their H II regions at a given fractional isophotal radius. We also conclude that neither dust nor ionizing field is the prime cause of this segregation.

We have also used an empirical calibration between excitation and abundance to measure the abundance gradients in these five galaxies. The agreement between our results using the empirical calibration of log([O III]/Hβ) and those of previous authors using detailed models and the calibration of log(([O II] + [O III])/Hβ) demonstrates that excitation can be used to measure abundance gradients as accurately and precisely as previously, provided measurements for many H II regions are used. M 51 apparently has a shallower gradient than the other galaxies, which we propose might be a result of the interaction with NGC 5195. Future work will include further analysis of the cause of the two populations, analysis of azimuthal variations in excitation and abundance, and a corresponding study of earlier-type galaxies.

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